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Abstract: We set out to test the hypothesis of right-hemisphere superiority for the implicit detection of a rule. Forty healthy men provided speeded manual responses to randomly presented digits from 1 to 6 (left hand to 1-3, right hand to 4-6). Red digits on trial n signaled that the response on trial n+1 should be made with one hand, blue digits with the other hand. White digits gave no signal (control trials). Half the participants were told that the stimulus color conveyed a rule that could be exploited to improve performance, the other half were not. After completing the first run, participants' awareness of the presence and nature of the rule was assessed and all were debriefed. Participants then performed a second run with identical stimulus conditions. In Run 1, none of the participants reported being aware of the nature of the rule. Reaction times (RTs) were longer after signal than no-signal trials, but only for the left hand. Participants informed about the presence of a rule tended to have longer RTs, irrespective of hand. In Run 2, RTs were shorter after signal than no-signal trials, and there were no differences between hands. The observed RT effect for the left-hand points to a right-hemisphere superiority for the detection and application of a rule in the absence of verbal awareness. Longer (instead of shorter) RTs in the signal trials are discussed in the framework of interhemispheric inhibition.

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A left-hand superiority for the implicit detection of a rule

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Abstract

We set out to test the hypothesis of right hemisphere superiority for the implicit detection of a rule. Forty healthy men provided speeded manual responses to randomly presented digits from 1 to 6 (left hand to 1-3, right hand to 4-6). Red digits on trial *n* signaled that the response on trial *n* + 1 should be made with one hand, blue digits with the other hand. White digits gave no signal (control trials). Half the participants were told that the stimulus color conveyed a rule that could be exploited to improve performance, the other half were not. After completing the first run, participants' awareness of the presence and nature of the rule was assessed and all were debriefed. Participants then performed a second run with identical stimulus conditions. In Run 1, none of the participants reported being aware of the nature of the rule. Reaction times (RTs) were *longer* after signal than no-signal trials, but only for the left hand. Participants informed about the presence of a rule tended to have longer RTs, irrespective of hand. In Run 2, RTs were *shorter* after signal than no-signal trials, and there were no differences between hands. The observed RT effect for the left hand points to a right hemisphere superiority for the detection and application of a rule in the absence of verbal awareness. Longer (instead of shorter) RTs in the signal trials are discussed in the framework of interhemispheric inhibition.

Keywords: Implicit learning; Choice reaction time; Hemispheric differences; Verbal awareness; Interhemispheric inhibition

1. Introduction

As "intuitive statisticians", we all use regularities experienced in the past to make predictions about the future. These inferences are sometimes based on evidence we are able to accurately verbalize. More frequently than not, however, we base our decisions on hunches that remain inaccessible to verbal awareness. There is converging evidence from various fields within experimental psychology that human participants are in fact able to learn the statistical structure of event sequences without being able to formulate the rule they appear to have grasped (Hake and Hyman, 1953; Bischoff-Grethe et al., 2000; Spiegel and McLaren, 2006; for overviews, see Reber, 1993; Stadler and French, 1998; Shanks, 2010).

In implicit sequence learning paradigms, evidence for successful motor performance in the absence of verbal access to the learned rule is reminiscent of "unconscious perception" after commissurotomy. In classic split-brain experiments, objects palpated with the left hand may later be recognized nonverbally, but they cannot be named because the tactile information is primarily represented in the right hemisphere and cannot readily pass to left hemisphere language areas. In participants with a fully functional corpus callosum, dissociation between motor performance and verbal monitoring can be provoked by lateralized stimulus presentation in the millisecond range (e.g., Landis et al., 1981). But even with central visual field stimulation, speeded manual responses allow inferences about hemispheric processing. "Divided-output methodology" (Root et al., 2006) requires participants to provide speeded unimanual responses to different aspects of a foveally presented stimulus. For instance, in a series of experiments by Root et al. (2006), participants used one hand to respond to a happy face and the other hand to respond to an angry face in randomized sequences of happy and angry faces. Faster right-hand responses to happy faces and faster left-hand responses to angry faces led the authors to conclude that the left hemisphere reacts faster to positive, approach-inviting facial expressions, whereas the right hemisphere responds faster to negative expressions. Root et al. (2006) employed the above methodology to investigate hemispheric laterality specific to response preparation, and an identical paradigm has been used to make inferences about hemisphere-specific cognitive processing at the perceptual level. For example, Keenan et al. (1999; 2000a; 2000b), and more recently Ma and Han (2010), found a left-hand reaction-time advantage specific to photographs of one's own face compared to the faces of others. From this finding, they deduced right hemisphere superiority for self-face recognition and, by inference, for other aspects of one's own self.

In the present study, we chose the divided-output method to investigate hemispheric differences in the implicit learning of sequential information. The observation of reliable manual responses to left-lateralized stimuli in the absence of verbal insight (Landis et al., 1981) led us to speculate that implicit learning of a statistical regularity could also be mediated by the right hemisphere, as demonstrated by a reaction-time advantage for the left hand. Right hemisphere superiority for implicit learning was suggested more than 15 years ago (Hugdahl, 1995), but to the best of our knowledge this hypothesis has never been tested in the framework of the unimanual learning (left versus right hand) of a sequence, the characteristics of which a participant cannot describe verbally. Of relevance to the issue of hemispheric differences in unconscious learning are some neuroimaging studies. These have provided evidence for *left* hemisphere mediation even of implicit knowledge about sequential information. However, the paradigms used in these studies required participants to learn a recurrent sequence of motor responses (Wilkinson et al., 2009) or an artificial grammar (DeVries et al., 2009). Involvement of the left hemisphere may thus have reflected primarily *motor* superiority for the analysis of short sequences resembling linguistic patterns. When the statistical information to be learned was embedded in strings of pictorial glyphs or visual-spatial configurations, a right hemisphere superiority has indeed been found (Turk-Browne et al., 2008; Roser et al., 2010). This superiority was assumed to manifest at the perceptual rather than conceptual level of processing (Roser et al., 2010).

In the present study, we used *temporal* regularity rather than *spatial* configurations to represent the rule. We presented healthy right-handers with a pseudorandom sequence of the digits 1 to 6 and had them perform a choice reaction time (RT) task. Specifically, we asked them to provide a speeded right hand response to digits 4, 5 and 6 and a speeded left hand response to digits 1, 2 and 3. The digits were white, red, or blue. Unbeknown to the participants, the red and blue digits always signaled which hand would be used for the next trial, whereas white conveyed no such signal. Under the assumption of right-hemisphere superiority for detecting this rule in the absence of awareness, we predicted faster and more accurate performance with the left hand than with the right hand.

A second prediction was based on the finding that conscious monitoring can attenuate implicit learning. In an fMRI experiment, Fletcher et al. (2005) investigated the effects of informing participants about the presence of a sequential rule on implicitly learning this rule. They found an effect they called the “benefit of not trying.” Participants who, before being exposed to a sequence, were informed that there was a rule to be learned, performed more poorly than participants who were expecting no sequential constraints. In the present experiment, half the participants were informed that color gave information about how to respond on the next trial and the other half were not. We hypothesized that only left hand performance would profit from a benefit of not trying or, in other words, that the performance of the left hand / right hemisphere, but not that of the right hand / left hemisphere, would be disrupted by informing participants about an underlying contingency.

2. Methods

2.1. Participants

Forty adult men were recruited by a flyer describing "an experiment about the speed of the two hands in reacting to digits." They were all right-handed (Chapman and Chapman, 1987) and none had a history of neurological or psychiatric disease, learning disabilities, or substance abuse (Campbell, 2000). Their vision was normal or corrected to normal, and none had any difficulty with color vision. The mean age was 34.0 years (SD = 12.5 years), and the mean years of formal education was 14.3 (SD = 1.8). All participants gave written informed consent before taking part in the study, which had been approved by the local ethics committee.

2.2. Stimuli and task

The stimuli were the digits 1 to 6 presented one-by-one in a pseudorandom order with the constraint that each digit appeared equally often. The digits were displayed in Georgia bold font (size 200) in the centre of a computer screen (black background) for 1500 msec or until a manual response was made. There were 144 trials, each initiated 1000 msec after the participant's response. 50% of the digits were white, 25% red, and 25% blue. The colors of the digits changed pseudorandomly from trial to trial, with the constraint that there were an equal number of "small" numbers (1, 2 and 3) and "large" numbers (4, 5 and 6). Trials with a white number were followed randomly by a trial with either a small or a large number. Trials with a red number were always followed by a trial with a small number, and trials with a blue number were always followed by a trial with a large number. The participants' task was to respond to numerically small numbers with the left hand ("F" key) and to numerically large numbers with the right hand ("J" key). We deliberately refrained from switching this contingency after half of the trials, as we were not interested in spatial-numerical interactions (Dehaene et al., 1993); rather, we wanted to ensure compatibility throughout between number magnitude and hand. The 144 critical trials were preceded by 18 practice trials that were not analyzed. The computer program (written in e-prime) recorded the correctness and RT of the manual response for each trial.

Insert Figure 1 about here

2.3. Procedure

Participants were assigned alternately to one of two instruction groups in the order they came to the session. Group 1 ("uninformed") was told that the color of the digits would not matter in the present experiment (i.e., the colors were left over from a previous study where they were relevant) and should therefore not be attended to. Group 2 ("informed") was told that the red and blue digits contain "some information that might help to speed up manual responding" and that, after the task, they would be asked whether they were able to determine what this information was. Irrespective of group assignment, all participants received the instruction to respond with the left hand to digits 1 to 3 and the right hand to digits 4 to 6, irrespective of color. Speed and accuracy were emphasized equally.

After the task, participants' awareness of the signaling property of color was carefully assessed by a two-page questionnaire, modified on the basis of Martin and Alsop (2004), with progressively more detailed questions about the critical rule (Appendix). This assessment was followed by a complete oral and written debriefing, which ensured that each participant clearly understood the contingencies (red and blue digits always signaled the correct response hand for the next trial and white digits never did). Each participant then completed a second run that was identical to the first run, except that full awareness of the contingencies was guaranteed.

2.4. Data analysis

Data from Run 1 (implicit rule learning) and Run 2 (conscious application of the rule) were analyzed separately in two planned ANOVAs with percent correct responses and reaction times of correct decisions, respectively, as the dependent variables. In both analyses, there were two within-subjects independent variables: "hand" (left vs. right) and "predictability" (colored vs. white digits). The ANOVA for Run 1also included a between-subjects variable, "information group" (participant knew about the presence of a rule vs. did not know about it).

3. Results

No participant demonstrated even the slightest awareness of the rule "color predicts response hand" or assumed any systematic relationship between digit color and any parameter of the presentation schedule. To the specific question, "Did you note any relationship between the color of the digit and whether you were to respond with your left or right hand?" one participant incorrectly stated that "red and white digits were frequently alternating, and blue occurred less frequently overall." All 40 participants responded "no" to the question, "Do you think that the digit, which was presented *after* a digit of a given color (white, red, or blue), had to be responded to with one rather than the other hand?" The awareness questions are reproduced in the Appendix 1.

Insert Table 1 about here

Insert Figure 2 about here

3.1. Run 1: No awareness of rule

Table 1 lists separately the percentages of correct decisions for the two information groups (informed vs. uninformed), predictability (white vs. red or blue), and hand (left vs. right). An ANOVA (first run) with Information Group as the between-participants factor and Predictability and Hand as repeated measures revealed only a main effect for Hand ($F(1,38) = 7.5$, $p < .01$), indicating better performance with the left hand. All other main effects and interactions were associated with $F < 1.5$ and $p > .23$. As shown in Table 1, the only significant difference between the two hands in the percentage of correct decisions was for signaled trials in the uninformed group ($t(19) = 2.7$, $p < .015$).

An analogous ANOVA (first run) for the RTs of correct decisions (see Fig. 2) revealed a significant main effect for Predictability ($F(1,38) = 12.0$, $p < .005$), with *longer* responses after signaled than after nonsignaled trials. The main effect of Information Group bordered on significance ($F(1,38) = 2.7$, $p = .11$). In each separate condition (informed versus uninformed), the informed participants had longer RTs than the uninformed participants. The interaction between Hand and Predictability was also significant ($F(1,38) = 6.2$, $p < .02$). RTs after signaled and nonsignaled trials were similar for the right hand ($t(39) = .5$, $p > .63$), but for the left hand RTs were significantly *longer* after signaled trials than after nonsignaled trials ($t(39) = 4.17$, $p < .0005$). See the left panel of Fig. 2. No other main effects or interactions were significant (all F ratios < .66 and all p values > .42).

3.2. Run 2: Awareness of rule

Table 1 lists the percentages of correct decisions in Run 2 separately for each predictability level and each hand. An ANOVA (second run) on these percentages with Predictability and Hand as repeated measures revealed no significant main effects or interactions (all F ratios < .2 and all p values > .69). An analogous ANOVA (second run) of the RTs of correct decisions (see Fig. 2) revealed a highly significant main effect of Predictability ($F(1,38) = 28.8$, $p < .0001$), with RTs *shorter* after signaled trials than after nonsignaled trials. There was no main effect for Hand ($F(1,38) = .51$, $p > .45$) and no interaction between Hand and Predictability ($F(1,38) = 2.8$, $p = .101$). See the right panel of Fig. 2.

4. Discussion

We required right-handed participants to perform a choice reaction-time task with bimanual responses to the digits 1 to 6 randomly presented in the center of a computer screen and differently colored. The left hand always had to be used to respond to small numbers (1 to 3) and the right hand to large numbers (4 to 6), that is, a compatible hand-number size arrangement (Dehaene et al., 1993). In a first run, unbeknown to the participants, one color (red or blue) always signaled a left-hand response on the next trial, the other a right-hand response. White numbers (50% of stimulations) were followed randomly by a small or a large number. In a second run, these contingencies and signaling were exactly the same, but participants were consciously aware of the contingencies.

For Run 1, we found that left-hand RTs differentiated between signaled and non-signaled trials but right-hand RTs did not. Accuracy was also higher for the left than the right hand. Overall, RTs to signaled trials were *longer* than to non-signaled trials—in strong contrast to our expectation of faster RTs after signaled trials. This RT pattern was the most puzzling finding of the present study, as in almost all previous experiments on implicit sequence learning a *facilitation* of RTs by the signaling cue was observed. The fact that signaling markedly slowed RTs in the present study is interpreted as the consequence of an active inhibition process. We discuss this process after addressing three other findings: (1) the observed differences between the two hands, (2) the impact of the instructional manipulation, and (3) the effects observed in the second run, after the participants had been informed of the rule "color predicts response hand."

4.1 Left-hand advantage in the implicit detection of the rule

Although accuracy was close to 100% (ranging from 95.9% to 98.8% across conditions), performance was significantly better with the left hand than the right hand only on the signal trials (red or blue), not the control trials (white). Only the main effect for hand was significant, not the interaction between signaling and hand. (see Table 1). This left-hand "sensitivity" was significant, however, only if the participants were not instructed to look for any rule (see section 4.2). This better performance with the left hand (higher accuracy and a significant RT difference between signaled and unsignaled trials) probably reflects a right hemisphere cognitive advantage in the sense of a superior ability of the right hemisphere to recognize the regularity in the sequence of stimuli. This interpretation is in accordance not only with early speculations based on the dichotomy between conscious and unconscious learning (Hugdahl, 1995), but also with recent split-brain data (Roser et al., 2010). In the latter study, a patient with a transsected corpus callosum could detect statistical regularity only in the left visual field; right visual field performance (and verbal awareness) were at chance.

At first glance, inferences about hemispheric differences in cognitive processing from the superiority of one hand over the other may not seem warranted in healthy subjects with an intact corpus callosum. However, the divided-output methodology we used here has previously been applied successfully in laterality research with healthy participants. Keenan and collaborators (e.g. Keenan et al., 2000a) and Ma and Han (2010, Exp. 3) employed it to illustrate a right-hemisphere advantage for self-face recognition, and Root et al. (2006) used it to demonstrate hemispheric differences in the reaction to approach- versus withdrawal-related emotional facial expressions. Strictly speaking, hand differences in RT do not by themselves prove hemispheric differences at any cognitive stage, but together with (1) greater accuracy for the left hand (in the absence of a significant RT-accuracy tradeoff) and (2) specificity of the left-hand advantage on signaled trials, inferences about right hemisphere involvement beyond the response-planning stage do not seem farfetched.

Although we are not aware of any previous experiments comparing the ability to learn a rule using the right or left hand in the absence of verbal awareness, there are isolated reports of findings that allow some inferences about left hand motor learning. Implicit sequence learning using the left hand was investigated in a PET study in which learning was found to be comparable to that established in earlier studies investigating right-hand performance (Grafton et al., 2002). The activation patterns suggested a prominent role of the left hemisphere (mainly the lateral prefrontal cortex and SMA) surprisingly similar to the regions activated in analogous learning with the right-hand. In an experiment on bimanual sequence learning, two uncorrelated repeating sequences had to be learned using either the right or left hand in a serial RT task. The authors found evidence for "separate learning modules for the left and the right hand" (p.152), which they labeled "embodied sequence learning" (Berner and Hoffmann, 2008). Which hand is governed by which hemisphere was not of much interest to these investigators; at least they did not offer an explanation of unimanual rule detection in terms of hemispheric specialization. In both reports (Grafton et al., 2002; Berner and Hoffmann, 2008), repeated 5 or 6 fixed-element sequences had to be learned motorically using one hand. This implicit sequence learning paradigm diverges in several important ways from that used in the present experiment. Our bimanual choice RT paradigm did not demand complex sequencing between individual fingers—a task for which the left hemisphere is specialized, even for the ipsilateral hand (Wyke, 1971; Schluter et al., 1998); rather, it required the operation of only one key per trial, using either the left or right hand. Each hand was always assigned the same key and the response criterion was

the magnitude (1, 2 or 3 vs. 4, 5 or 6) of the exposed number. What had to be learned was the rule "color predicts hand." No stimulus sequence was repeated during the experiment and no repeating motor pattern was therefore expected, even in the case of perfect learning. This means that at stake was not the learning of a sequential pattern hidden in the stimulus series, but rather the detection of a rule pertaining to one of two stimulus attributes (red signals one hand, blue signals the other). However easy to articulate in retrospect (i.e., after debriefing), this rule appeared to have remained inaccessible to the left-hemisphere-mediated verbal awareness of our participants.
It may well be that this fixed, non-probabilistic association was captured by the illiterate right hemisphere, which is known to be specialized for the detection of global configurations (e.g., Tucker, 1981; Roser et al., 2010). Even in language processing, the right hemisphere's inferior performance at the level of the single word may be offset at the discourse level by a superiority for appreciating global context (e.g., Jung-Beeman, 2005).

A dissociation between manual performance and verbal awareness similar to ours was previously found when a *divided-input* paradigm involving faces was applied (Landis et al., 1981). However, in our experiment, the predictive attribute of the stimulus (color) could not be detached from the stimulus itself and and presented to the left or right visual field. Lateralization of the stimulus numbers would have unnecessarily complicated the situation by introducing incompatibilities e.g. a small number presented to the right visual field would unavoidably have introduced a Simon effect (Tlauka, 2002). We were thus forced to employ a *divided-output* methodology. We suggest that the paradigm we used may prove fruitful for future studies of the lateralized processing of sequential information.

4.2. The inhibitory effects of conscious expectations

Half our participants were randomly assigned to an "informed" group that was told that the colors would signal a rule that could be exploited to improve performance. In line with previous findings from a study with an identical information manipulation (Fletcher et al., 2005), we found a “benefit of not trying” effect, which means that participants thus informed showed poorer performance (see also Custers and Aarts, 2011) than those who were informed. Although the interaction between information group and signaling did not reach conventional levels of significance for the percentage of correct decisions, the effect of the signaling property of the colors was significant only for those participants who assumed that the task was intended to assess nothing more than manual response speed to randomly presented digits (i.e. the uninformed group). The fMRI results of Fletcher et al. (2005) suggest that the performance decrement they found in connection with the conscious search for patterns was due to right frontal activity that arguably interfered with activity in the medial temporal lobe and thalamus. Such inhibitory activity could likewise have lengthened our participants' RTs, the analysis of which revealed a clearly significant interaction between information group and signaling. Alternatively, it can be argued that the conscious search for a rule is mediated primarily by the left hemisphere (Wolford et al., 2000), which may have interfered with the hunch-like detection strategy of the right hemisphere, which, although fast, can easily slow down once its decisions are questioned by the much slower verbal system.

4.3. Explicit application of the rule

The plausibility of this latter interpretation can be further enhanced by examining participants' performance in the second run, in which they were fully and explicitly informed about the simple rule "color predicts response hand." The signaling cues did not influence performance accuracy, nor was there an advantage of one hand over the other. The absence of any effects on decision accuracy is most likely due to a ceiling effect in the manual performance. However, in terms of response latencies, the effect of signaling was extremely powerful and less counterintuitive in terms of direction than it was during the implicit detection of the rule. RTs were much faster after signal trials than after control trials. Although this result by itself is trivial, it nevertheless validates the procedure (i.e., once explained, the rule was not difficult to follow, and it also was very effective in speeding up the responses in those trials where the rule applied). In accordance with our prediction that specifically the *non*-conscious detection of the regularity would be under right hemisphere control, there was no left hand advantage in this fully conscious application of the color-hand rule.

4.4 Why longer RTs for an implicitly captured rule?

The question remains why, in contrast to almost all other investigations of implicit learning[1], were the critical trials in run 1 followed by *slower* responding, at least by the left hand, which was the only one to differentiate (in terms of RT) between signal and no-signal trials? We think it is possible, as is the case with performance decrements induced by the conscious search for a rule, that a conflict between the two fundamentally different information processing strategies of the two hemispheres produced the increase in RTs. The left hemisphere shows a preference for analytical processing, whereas the right hemisphere is more specialized for dealing with global, fuzzy analysis (see Tucker, 1981, for an early overview). Although the global rule "color predicts hand" could have been grasped by the left hand / right hemisphere at the

[1] But see Custers and Aarts (2011; Exp. 2) for an exception. The *longer* RTs they found to critical items was that puzzling to them that they considered it a fluke (p.374).

beginning of the task, the left hemisphere may have been confused on individual trials. It is well known that the left hemisphere has motor control over both the right and left hand (see Wyke, 1971, and Haaland et al., 1987, for the clinical evidence; Kim et al., 1993, and Schluter et al., 1998, for magnetic stimulation and neuroimaging evidence), and it plays a crucial role in the selection of the hand to be used during unimanual motor actions (Oliveira et al., 2010). Left hemisphere motor control combined with right hemisphere dominance in apprehending the global rule thus may have produced an interference effect, especially for the left hand. Which response to choose may thus have been determinable by the right hemisphere but not by its left counterpart, which was more concerned with the motor particulars of generating whatever response was chosen. This account of interference at the motor output level is consistent with the proposal of late-stage inhibition as the mechanism responsible for negative compatibility effects in subliminal priming (Klapp and Hinkley, 2002; see Eimer and Schlaghecken, 2003, for a review). Inhibitory effects on RTs were also described in an experiment requiring lexical decisions in response to centrally presented letter strings (Lambert and Voot, 1993). These central strings were flanked by parafoveally flashed words that were not attended to by the participants and which, in some trials, showed a semantic relationship to the centrally located target word. In the absence of conscious processing, words presented in the *left* visual field led to slower RTs to the central word when the two stimuli were semantically related. No comparable inhibition effect was present in the case of right visual field flankers. Although the methodologies in this and the present experiment were very different, the similarity in the observed inhibition effect is telling. In both instances, inhibitory activity was confined to right hemisphere processing (inferred by left visual field or left hand performance, respectively) and contingent on participants' unawareness of the cue producing the putative inhibition (semantic relatedness or presence of a rule).

5. Alternative accounts

To our knowledge, our use of divided-output methodology in the study of implicit rule learning is unprecendented. Therefore, we briefly consider potential artifacts of the procedure that might suggest differential involvement of the two hemispheres in the detection of a rule when no such differences actually exist. First of all, hand differences in motor speed do not necessarily translate into cognitive processing differences between the hemispheres. The hand differences we found could indicate nonspecific vigilance or differential motor practice effects (Wickens and Sandry, 1982). Moreover, in the context of implicit learning, they could reflect hemispheric differences in response planning rather than in the detection and application of a sequential rule. Especially in view of our paradoxical finding of prolongation rather than facilitation of RTs in critical trials, the possibility of certain interactions must be considered that do not necessarily imply a better *detection* of a statistical regularity by one or the other hemisphere. In section 4.4, we mentioned a potential interhemispheric interference effect at response-selection stage, but intrahemispheric inhibitory mechanisms could play a role as well. Such mechanisms have been described as a joint function of the hippocampus (potentially a locus of chunking in the learning of sequences) and the basal ganglia (crucial for the motor aspects of sequence learning) (Lieberman et al., 2004). If organized asymmetrically, such within-hemisphere inhibitory processes could well lead to hand differences in motor speed.

Also of note is the fact that, to keep the response requirements as simple as possible, we ensured that the number-magnitude/hand assignment was always compatible (i.e. the left hand responded exclusively to small numbers, the right to large). This asymmetry in our experimental design, although not optimally elegant from a theoretical standpoint, is unlikely to have produced spurious results. One would assume that neither hand can take advantage of a consistent compatibility between body space and number space *exclusively on signaled trials*.

6. Suggestions for further research

Although our experiment produced evidence for right hemisphere superiority for the implicit detection of a simple rule, it generated one unanticipated and even couterintuitive finding: successful application of the rule was accompanied by an *increase* rather than a decrease in RTs to critical trials. We have interpreted this slowing of a motor response as a consequence of interhemispheric inhibition, but we readily admit that this interpretation is necessarily speculative. It may be revealing to examine the time course of this hypothetical inhibition effect in future electrophysiological explorations. Evoked-potential paradigms and the monitoring of error-related negativity seem especially promising. The collection of event-related fMRI data from participants engaged in our simple choice RT task could help disentangle the purportedly facilitative right hemisphere components of rule grasping and the hypothetical inhibitory left hemisphere components of response execution. Alternatively, if the association of the right prefrontal cortex with inhibitory processing (Fletcher et al., 2005) is in any way relevant to the slowing down of manual responses, repetitive transcranial magnetic stimulation over this site might produce a temporary breakdown in inhibitory processing. In this case, the deceleration of the RTs (a form of "negative priming") observed in the present experiment could perhaps be turned into a facilitation effect.

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Appendix 1

Awareness Assessment Questionnaire

(1) What do you think: how many digits did you have to respond to in total?

(2) What do you think was the goal of the present experiment?

(3) Did you note any difference in the way you responded with your left and with your right hand? □ no □ yes (please specify)

(4) Did you note any regularity ...

(a) ... in the sequence of white digits? □ no □ yes (please specify)

(b) ... in the sequence of red digits? □ no □ yes (please specify)

(c) ... in the sequence of blue digits? □ no □ yes (please specify)

(5) Did you note any relationship between the color of the digit and whether you were to respond with your left or right hand? □ no □ yes (please specify)

(6) Could you detect the different colors (white, red, or blue) equally well?

□ yes □ no (please specify)

(7) Do you think that the digit which was presented *after* a digit of a given color (white, red, or blue) had to be responded to with one rather than the other hand?

□ no

□ yes; after a white digit, the probability that the left / right hand (please circle) had to be used was greater than 50% (i.e., chance), I estimate around ___% (please fill in)

□ yes; after a red digit, the probability that the left / right hand (please circle) had to be used was greater than 50% (i.e., chance), I estimate around ___% (please fill in)

□ yes; after a blue digit, the probability that the left / right hand (please circle) had to be used was greater than 50% (i.e., chance), I estimate around ___% (please fill in)

(8) Are there any other thoughts about the task you would like to let us know about?

Figure Legends

Fig. 1 – Sequence of sample trials of the implicit rule detection task that required participants to provide speeded unimanual responses to randomly presented digits between 1 and 6 (left hand always to "small" numbers 1-3, right hand to "large" numbers 4-6). In the present case, red (here printed black) predicts a small number on the next trial, and blue (here printed grey) a large number**;** this assignment was reversed for half of the participants. White digits (50% of trials, like red and blue digits evenly distributed over the numbers 1 to 6) were control stimuli (i.e.**,** were followed by a small or a large number with equal frequency).

Fig. 2 – Interaction between hand and predictability. Left panel: during implicit application of the rule, left hand RTs were longer after signaled compared to nonsignaled trials. No comparable difference was observed for the right hand. Right panel: during explicit application of the rule, RTs were shorter after signaled trials for both hands. Error bars represent standard deviations.